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Vertical Coupling and Variability in the Tropical Atmosphere/Ionosphere System

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14. ABSTRACT

The main objective of this research was to understand the processes that dynamically couple the troposphere at equatorial/tropical latitudes with the overlying thermosphere-ionosphere, and identify those aspects of ionospheric variability which may be directly attributable to these processes. Using a combination of data analyses and numerical simulations, a new understanding of the excitation mechanisms, propagation characteristics, and lower thermosphere perturbations relating to tropospherically-excited Kelvin waves and nonmigrating tides has been developed. In addition, an analyses of ionospheric data was completed that provides an estimate of the "meteorological" contributions to ionospheric space weather.

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FINAL REPORT
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Research Title: Vertical Coupling And Variability In The Tropical Atmosphere/Ionosphere System

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Objectives and Summary of Accomplishments: The main objective of this research was to understand the processes that dynamically couple the troposphere at equatorial/tropical latitudes with the overlying thermosphere-ionosphere, and identify those aspects of ionospheric variability which may be directly attributable to these processes. Using a combination of data analyses and numerical simulations, a new understanding of the excitation mechanisms, propagation characteristics, and lower thermosphere perturbations relating to tropospherically-excited Kelvin waves and nonmigrating tides has been developed. In addition, an analyses of ionospheric data was completed that provides an estimate of the "meteorological" contributions to ionospheric space weather.

Summary of Results:

Hourly foF2 data from over 100 ionosonde stations during 1967-1989 were examined to quantify F-region ionospheric variability, and to assess to what degree the observed variability may be attributed to meteorological influences, as well as to variations in solar ionizing flux and solar wind conditions. This is the first study of its kind, to globally ascertain the variability of the ionosphere and to attempt to broadly categorize the sources of variability. Our findings are as follows. Under quiet geomagnetic conditions (Kp < 1), the 1-s (s =standard deviation) variability of N_{max} about the mean is ~Ò25-35% at 'high frequencies' (periods ~hours to 1-2 days) and ~Ò15-20% at 'low frequencies' (periods ~2-30 days), at all latitudes. These values provide a reasonable average estimate of ionospheric variability due to "meteorological influences" at these frequencies. Changes in N_{max} due to variations in solar photon flux , are, on the average, small in comparison at these frequencies. Under quiet conditions for high-frequency oscillations, N_{max} is most variable at anomaly peak latitudes. This may reflect the sensitivity of anomaly peak densities to day-to-day variations in F-region winds and electric fields driven by the E-region wind dynamo. Ionospheric variability increases with magnetic activity at all latitudes and for both low and high frequency ranges, and the slopes of all curves increase with latitude. Thus, the responsiveness of the ionosphere to increased magnetic activity increases as one progresses from lower to higher latitudes. For the 25% most disturbed conditions (Kp>4), the average 1-s variability of N_{max} about the mean ranges from ~Ò35% (equator) to ~Ò45% (anomaly peak) to ~Ò55% (high-latitudes) for high frequencies, and from ~Ò25% (equator) to ~Ò45% (high-latitudes) at low frequencies. Some estimates are also provided on N_{max} variability connected with annual, semiannual and 11-year solar cycle variations. This work is published (see list below).

Simulations of a 3-day ("ultra-fast") Kelvin wave were completed. Several interesting features of the Kelvin wave were revealed by the simulations, which were interpreted in terms of the effects of mean winds and dissipation on the wave. For instance, in classical atmospheric wave theory without dissipation, this wave is equatorially trapped and has small meridional velocities. In my simulations it is shown that in the dissipative thermosphere this wave has non-negligible meridional velocities

with *maxima at the poles*. In addition, westward (eastward) mean zonal mesospheric winds near the equator Doppler-shift the wave to higher (lower) frequencies and increase (decrease) its vertical wavelength, thus reducing (increasing) its susceptibility to dissipation. Winds asymmetric about the equator are found to *locally* distort the latitudinal shapes of the Kelvin wave fields by coupling into modes which tend to remain confined to the level of excitation. For realistic forcing, dissipation and mean wind configurations, it is shown that the Kelvin wave is capable of achieving amplitudes of order 10-25 K in temperature and 10-40 ms^{-1} in zonal wind in the 100-150 height regime, and producing zonal mean eastward accelerations of order 10-15 $ms^{-1}day^{-1}$. The Kelvin wave perturbations ought in addition to have significant effects on the dynamo generation of electric fields, layering of metallic ions, and on variations in various airglow emissions originating between 90 and 105 km. This work is published (see list below).

The effects of latent heat release due to deep tropical convection on solar tidal variability in the 80 - 150 km altitude region were examined. The latent heating estimates are based on 7-year mean monthly 3-hourly rainfall rates obtained through the Global Precipitation Climatology Project. The latent heating rates are used to force the Global Scale Wave Model (GSWM) to obtain monthly estimates of the migrating diurnal (zonal wavenumber s = 1), migrating semidiurnal (s = 2) and standing (s = 0) diurnal tidal oscillations. It was demonstrated that monthly variations of up to 20 ms^{-1} and 10 K are attributable to this excitation source, as well as longitudinal variations in the diurnal tide of order 15 - 25 ms^{-1} at peak amplitudes. This work is published (see list below).

The effects of tropospheric heating on diurnal tides at higher levels were examined in a wider context using total tropospheric heating rates (i.e., radiative, convective and condensation heating, and boundary layer heating) from the NCEP/NCAR Reanalysis Project. These heating rates were found to give rise to a semiannual variation in the migrating (sun-synchronous) tidal wind response near 95 km altitude with equinoctial maxima (~50-70 ms^{-1}) similar to those seen in observations. Nonmigrating (longitude-dependent) tides with zonal wavenumbers s = -3 (eastward) to s = +5 (westward) were also generated. Many of these oscillations are characterized by wind and temperature amplitudes of order 20-30 ms^{-1} and 10-20 K in the lower thermosphere (100-130 km), and suggest that the tidal response in this regime varies considerably with longitude. This work is published (see list below).

Publications:

- Forbes, J.M., M.E. Hagan, X. Zhang and J. Hackney, Upper atmosphere tidal variability due to latent heat release in the tropical troposphere, Adv. Space Res., 24(11), 1515-1521, 1999.
- Forbes, J.M., Wave coupling between the lower and upper atmosphere: Case study of an ultra-fast Kelvin wave, J. Atmos. Solar-Terr. Phys., in press, 2000.
- Forbes, J.M., S. Palo, and X. Zhang, Variability of the Ionosphere, J. Atmos. Solar-Terr. Phys., 62, 685-694, 1999.
- Forbes, J.M., X. Zhang, and M.E. Hagan, Simulations of diurnal tides due to tropospheric heating from the NCEP/NCAR Reanalysis Project, Geophys. Res. Lett., 28, 3851-3854, 2001.

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Invited Lectures, Presentations, Talks, etc.:

- Forbes, J.M., M.E. Hagan, X. Zhang and J. Hackney, Upper atmosphere tidal variability due to latent heat release in the tropical troposphere (Invited), COSPAR Assembly, Nagaoya, Japan, July, 1998.
- Forbes, J.M., and M.E. Hagan, Kelvin waves in the ionosphere-thermosphere system (Contributed), Spring Meeting of the AGU, Boston, MA, May, 1998.

- Forbes, J.M., and M.E. Hagan, Kelvin waves in the mesosphere and thermosphere (Contributed), IUGG, Birmingham, U.K., July, 1999.
- Forbes, J.M., S. Palo, and X. Zhang, Ionospheric Variability (Contributed), Spring Meeting of the AGU, Boston, MA, May, 1999.
- Forbes, J.M., An ultra-fast Kelvin wave in the mesosphere and thermosphere, Western Pacific Geophysics Meeting, Tokyo, Japan, June, 2000.

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